



Research and Development Department

ACOUSTIC NOISE CRITERIA FOR LISTENING ROOMS AND CONTROL ROOMS

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Summary

This Report is based on a submission document to both EBU G1(LIST) and ITU-R TG 10/3 drafting committees. It describes background noise criteria for high-quality listening environments from a number of different organisations and the derivation of a compromise criterion for the continuous background noise levels. The outcome of the work, and the proposal submitted to those technical groups, was the choice of an appropriate Noise Rating curve as a common standard. NR10 was found to fit well with other organisations' criteria. Some problems relating to the apparent demise of the former ISO Noise Rating curves are also discussed.

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1. INTRODUCTION

Broadcasters and other organisations throughout the world set standards for the maximum permitted levels of continuous extraneous noise which should exist in high-quality listening environments. This noise usually arises from the mechanical ventilation system for the room, but can have other components, for example, noise generated by the equipment in the room or even in an adjacent room. Because of the masking effect, these noise level standards also form the basis of calculations for the sound insulation required to enclose the room.

In efforts to reach agreed standards for the interchange of programme material and for the subjective testing of audio processing equipment, both the ITU-R (formerly CCIR) and the EBU have technical groups or working parties attempting to make recommendations for acoustic (and other) standards for the listening environment. At the time of writing, the EBU group preparing a recommendation for high-quality listening rooms is G1/LIST, and the ITU group preparing a recommendation for the subjective assessment of high-quality audio systems is TG10/3. These two groups are, as far as possible, attempting to harmonise their recommendations.

2. BACKGROUND NOISE CRITERIA IN GENERAL

The background noise criteria can take a number of forms. Most broadcasting and recording organisations have their own. These are generally designed to be suited to the requirements of studio and control-room areas. As would be expected for a common problem, there are significant similarities between the individual organisation's standards.

They all have the same general shape, essentially the inverse of the human ear's sensitivity characteristic at the appropriate absolute level.

As an alternative to individual standards, a commonly-used set of international standard noise criteria, the ISO Noise Rating curves¹, were sometimes used. These were also widely used in other industrial organisations, by noise control authorities, and by broadcasters and recording companies for non-programme areas. However, as a result of revisions, the ISO NR curves appear to have ceased to exist (see Appendix 1). In some parts of the world the ANSI

Noise Criteria curves are also commonly used² for the same purposes.

Usually, the criteria have a number of different option levels, the appropriate choice depending on the particular application of the room.

In preparation for the EBU and ITU meetings, a study was carried out to try to find a common agreed standard. This Report is, essentially, the submission document to those drafting groups. The purpose was to compare a number of such criteria with the objective of finding a compromise criterion, to be accepted as a uniform international standard for high-quality listening environments.

Most detailed acoustic measurements and calculations are carried out in a relatively small number of constant-percentage bandwidth frequency bands — either in octaves or in one-third octaves. This Report is restricted to discussions of one-third octave analysis.

It should be noted that the numerical values of the noise criteria will be different if converted to or measured in other bandwidths. Because of the gradient of the curves, especially at low frequencies, the conversion to other bandwidths is non-trivial (see Appendix 3).

3. THE CRITERIA IN DETAIL

Arising from a meeting of EBU G1/LIST, data for background noise criteria were received from IRT, OIRT and BBC. From each submission, the criterion appropriate for a listening room or control room was selected.

These criteria were ARD 1.11-1³, OIRT 51/1⁴ and BBC curve ii⁵. Because of tolerances and frequency range differences, these had to be manipulated to some extent to normalise them to a common basis.

An attempt was then made to convert all of the criteria into upper limits by adding, where appropriate, allowed tolerances.

3.1 IRT submission

The IRT submission was, in fact, the ARD standard AI 1.11-1, dated 1966. For this study, the specified relaxation allowance for control rooms

(which varies with the frequency band) has been added to the criterion for radio studios.

These criteria also include some additional tolerance figures. For the present purposes, these are complicated by having a number of different options, depending on the frequency range of the excess noise. For this work, the widest band (and lowest amplitude) tolerance of 2 dB has been added over the range 250 Hz to 8 kHz.

The frequency range of the original standard was from 50 Hz to 10 kHz. For compatibility with the other data, the lowest two bands, 31.5 and 40 Hz have been extrapolated from the values for higher frequencies.

3.2 OIRT criteria

The OIRT submission was 51/1 (TK-29-116), dated August 1988. Of the seven criteria given in the standard, Number 3 appeared to be the one most appropriate for listening rooms and control rooms. In the absence of tabular values for 1/3rd octaves, the data was transcribed from the graphical presentation. This will have undoubtedly introduced small errors.

The values in TK-29-116 are for octave band analysis. The proper conversion of such data to one-third octave bands is non-trivial (see Appendix 3). For the purposes of this work, the values were read from the graph at one-third octave intervals and 5 dB subtracted from each one. As a result of this simplistic octave-to-1/3rd-octave conversion, the values will have been about 2 - 3 dB too high at the lowest frequencies, and too low (by a nominal 0.23 dB) at the higher frequencies.

The values are maximum levels. The frequency range covered is from 31.5 Hz to 16 kHz.

3.3 BBC criteria

The BBC criterion curve ii (covering most studios and control room areas) was selected as most appropriate. The BBC curves are formally specified in 1/3rd octaves from 50 Hz to 4 kHz. However, an analytic function closely approximating the curves can be used to give values for any 1/3rd-octave frequency band.

The BBC criteria are maximum values.

3.4 Noise Rating curves

ISO R 1996¹ defined the Noise Rating curves in octave bands over the frequency range 31.5 Hz to 8 kHz.

Since that time, R 1996 has been revised to exclude any reference to the NR curves⁶. Technically, they have ceased to exist (see Appendix 1). Nevertheless, they are in common use in many parts of the world. For the purposes of this work, it has been assumed that they still exist as a *de facto* standard. ITU-R Task Group 10/3 took the view that, because of their value and applicability to the fields covered by ITU discussions, if the NR curves no longer existed as an ISO standard then the ITU would redefine the same curves in its recommendation. At the time of writing, this approach is still in draft form. It is not clear whether such an approach will be successful.

For the purposes of this work it is desirable to use 1/3rd octave values. These were not included in the original ISO specification (technically, because they were not specified, they could not exist at all). However, a set of values and analytic curves have been derived for both octave and 1/3rd octave bands (see Appendices 2, 3). NR 10 was taken to be reasonably comparable to the other criteria.

3.5 Threshold of hearing

The diffuse-field threshold of hearing data has been taken from the graphs in Ref. 7. They have been approximately adjusted to 1/3rd octave bands by subtracting 5 dB. The threshold has been included only as a guide to the potential audibility of the other criteria. It is not suggested that the threshold of hearing should form the proposed standard.

(As a matter of general interest, at the time of writing, a draft new standard for the diffuse-field hearing threshold is being prepared⁸. It has not yet been accepted either as an International Standard nor as a British Standard. The work reported here, and the data used, pre-date the distribution of that draft and differ significantly from it, especially at low frequencies.)

4. COMPARISON OF CRITERIA

Table 1 shows the numerical values of the criteria used for this work. The values are in 1/3rd octave band sound pressure levels, in dB relative to 20 μ Pa.

Fig. 1 shows the same data graphically.

4.1 Low frequencies — up to 200 Hz

At low frequencies there is very little difference between three of the criteria — OIRT, BBC and NR10. At about 80 Hz they are indistinguishable. Between about 100 and 315 Hz the BBC criterion is significantly higher than either the OIRT or NR10.

Table 1: Noise criteria in 1/3rd octave bands.

Freq.	ARD	BBC	OIRT	Thresh.	NR10
31.5	50	50.8	50	52	54.0
	46	45.0	46	46	47.8
	36.5	40.2	41	37	42.1
63	31	36.0	37	31	37
	25	32.4	32	26	32.4
	19.5	29.1	28	20	28.3
125	16.5	26.2	24	17	24.6
	14	23.6	22	14	21.4
	12.5	21.1	18	10	18.4
250	11	18.9	16.5	8	15.9
	10	16.8	14	5	13.5
	8	14.9	12.5	3	11.5
500	7.5	13.1	11	2	9.6
	7	11.3	9.5	1	7.9
	6.5	9.7	8	0	6.4
1 k	6.5	8.2	7.5	0	5.1
	6	6.8	7	0	3.8
	5	5.4	6	-1	2.7
2 k	4.5	4.1	5	-3	1.7
	4	2.8	5	-5	0.8
	3	1.6	5	-7	0.0
4 k	2.5	0.5	5	-7	-0.7
	2.5	-0.6	5	-5	-1.4
	1	-1.7	5	-1	-2.0
8 k	1	-2.7	5	2	-2.6
	1	-3.6	5	6	-3.1

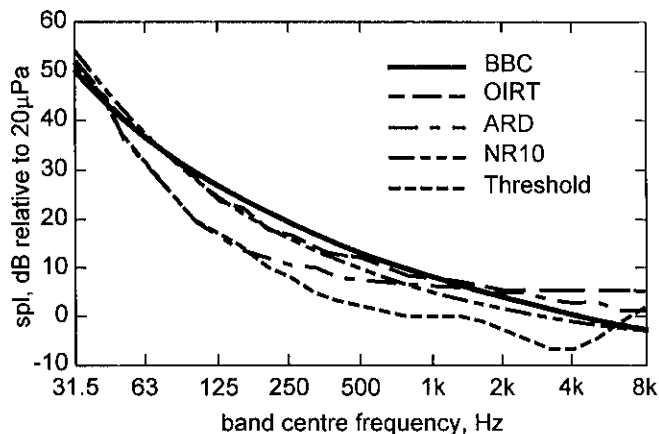


Fig. 1: Background noise level criteria.

The ARD criterion is different, being 10 dB below the others. At frequencies up to 160 Hz, it is essentially identical to the threshold of hearing.

4.2 Mid frequencies — 200 Hz to 1 kHz

In the mid-frequency range, the BBC and the OIRT criteria are similar and the ARD criterion makes a transition over this region from the threshold of hearing to values similar to the others. The NR10 curve is also similar over most of the frequency range.

4.3 High frequencies — above 1 kHz

At frequencies above 1 kHz, the OIRT and, to a lesser extent the ARD criteria become fairly constant and similar to each other. The BBC curve and the NR10 curve continue to fall to lower values. The BBC, OIRT and ARD criteria are essentially identical in the range 1.25 - 2 kHz.

The NR10 curve and the BBC criterion become identical again at about 5 kHz.

5. DISCUSSION AND RECOMMENDATION

It is clear from Fig. 1 that there is little substantial overall difference between the OIRT, BBC and NR10 criteria.

Considering the normal tolerances of air-conditioning system design, any one of these could be used as a satisfactory design specification for a listening room.

The ARD criterion is much more stringent than the others, specifying threshold-of-hearing levels at low frequencies. At higher frequencies, the levels are well above threshold. By definition, it could not sound neutral.

The Noise Rating curves were designed to give a reasonably neutral sound at any level. The large bass content would result in problems in studio areas, where the natural level of the sound might be enhanced by an overall system gain; in the context of a listening room or control room, where the sound is not further amplified, that consideration does not apply.

In terms of the difficulty and expense of an air-conditioning system meeting the standard, the ARD curve would be significantly harder and more expensive to achieve because of the much lower values in the 63 to 200 Hz range. This would probably require significantly larger primary attenuators, with their attendant higher pressure drop and increased fan power.

The differences at higher frequencies have little impact on the cost of the installation because the control of high frequency noise is relatively simple and cheap to achieve.

There would be advantages to be gained from the use of international standards, as they are already subject to international agreement. In this case, the NR10 curve appears to be a reasonable compromise between the individual standards. It is similar to all of the other standards over some parts of the frequency

range. It would result in a noise spectrum which was fairly neutral in character. It provides a reasonable compromise of performance and cost. In an octave version at least, it was specified in an industry-standard form, rather than requiring the use of a special set of numbers. It is also reasonably easy to achieve the curve shape with normal air-conditioning techniques. (It may be noted that the BBC curve was actually derived from achieved performances and therefore, by definition, is an example of what could be achieved. The NR10 curve is not so very much different in shape.)

6. CONCLUSIONS AND RECOMMENDATIONS

Four potential background noise criteria have been compared, after some adjustment to convert them to a common basis. These were control/listening room criteria from ARD, OIRT and the BBC, together with a Noise Rating curve.

The NR curve, in addition to already having been an agreed international standard, represents the main features, or a reasonable compromise, of the other criteria. It was recommended that the curve NR10 be used as the basis of the specification for a high-quality listening environment. To allow some degree of flexibility, it is possible that a range of criteria, say NR5 to NR15, could be specified, with a recommended preference for NR10.

As a footnote, at the time of writing the ITU draft includes the proposal to use the NR curve as the recommended noise level criterion and attempts to overcome the uncertainty of the Noise Rating status by including a re-definition of the NR curves. The EBU drafting group have elected to avoid the difficulty by specifying a single-figure 'A'-weighted measurement (20 dBA) as the standard. This is quick

and simple to measure and the numerical value chosen is comparable to the NR10 curve at mid and high frequencies. At low frequencies, however, the inverse 'A'-weighted spectrum at such a low level does not match the ear sensitivity curve. It is about 10 dB more demanding (i.e. lower noise levels) at 50 Hz, with consequential additional costs for the ventilation system design and for the degree of low-frequency sound insulation.

7. REFERENCES

1. ISO R 1996-1971. Assessment of noise with respect to community response. Appendix Y.
2. BERANEK, L.L., 1960. Noise reduction. London: McGraw-Hill, p. 518.
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4. Empfehlung Der Technischen Kommission DER OIRT, Nr. 51/1 (TK-29-116).
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7. ROBINSON, D.W. and WHITTLE, L.S., 1964. The loudness of octave-bands of noise. *Acustica*, 14, 1, 1964, pp. 24-35.
8. ISO/DIS 389-7 Acoustics — Reference zero for the calibration of audiometric equipment. Part 7: Reference threshold of hearing under free-field and diffuse-field listening conditions.

APPENDIX 1

The Status of the Former ISO R 1996 Noise Rating Curves

The situation regarding the status of the former ISO Noise Rating curves is far from clear. The present author has spent some time investigating the position, in discussing it with other interested parties and speaking to the Chairman of ISO TC43 (the relevant drafting body). What is presented here is a summary of the information and opinions gathered from these various sources. It is not necessarily correct, nor is it a formal statement of the official position.

In 1972 a set of noise spectra were defined by the International Standards Organisation¹. In 1983, the recommendation was revised to exclude any reference to the NR curves⁶. They are not defined in any other standard or recommendation. Had the revised recommendation been allocated a new number, then it could be argued that the previous one remained in force. By not renumbering the recommendation, the drafting group effectively withdrew the definition of the curves. Technically, they ceased to exist.

Nevertheless, they are in common use in many parts of the world. Few people realise that such is the position, and references to them continue to appear.

For the sake of future references, the Noise Rating curves may well be re-defined (identically) by the ITU.

The Figures defining the NR curves which appear in the ITU draft are reproduced here as Figs. A1.1 and A1.2 (*overleaf*). These Figures are embodiments of the defining equations described in Appendices 2 and 3.

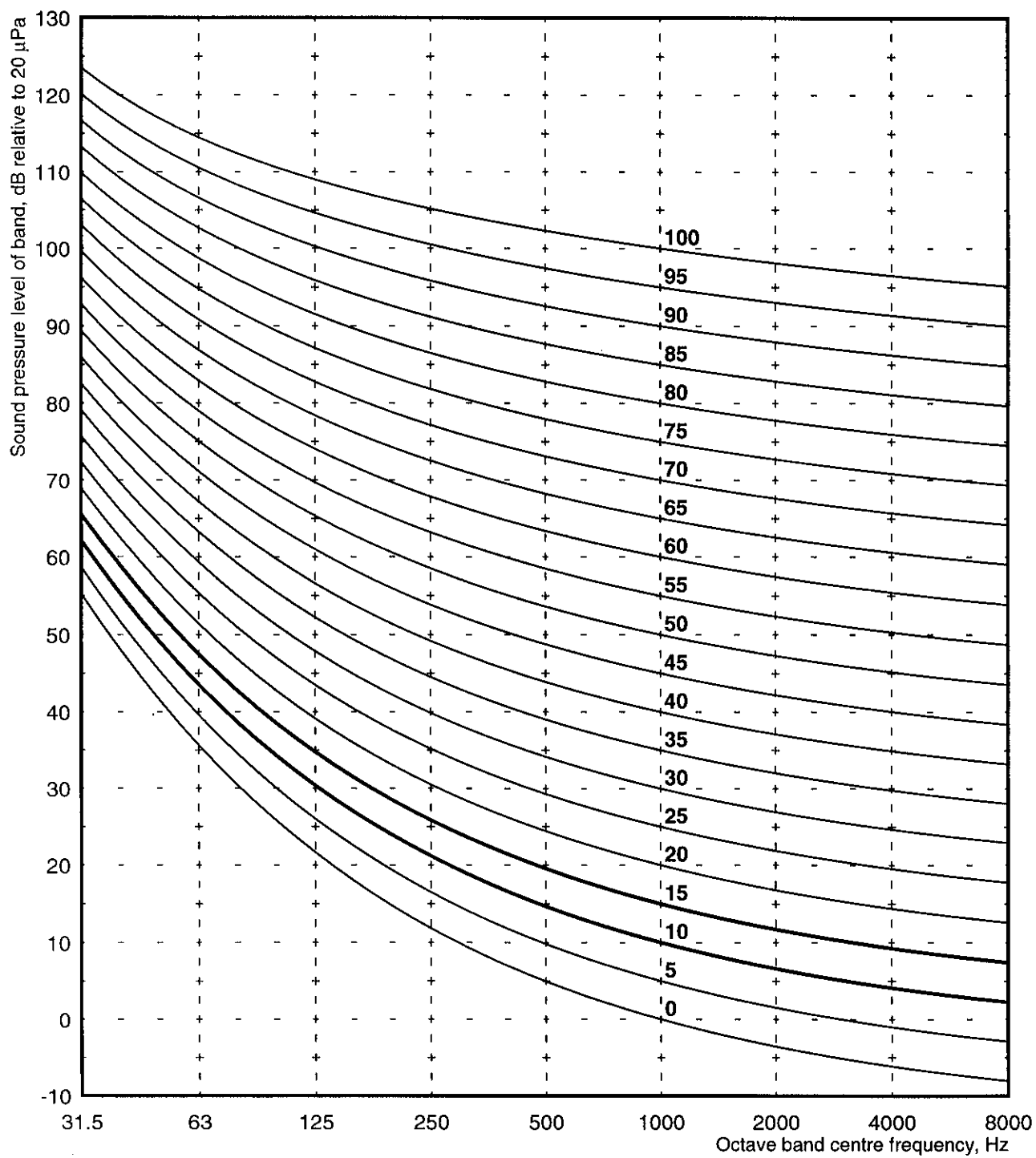


Fig. A1.1: Octave band Noise Rating curves.

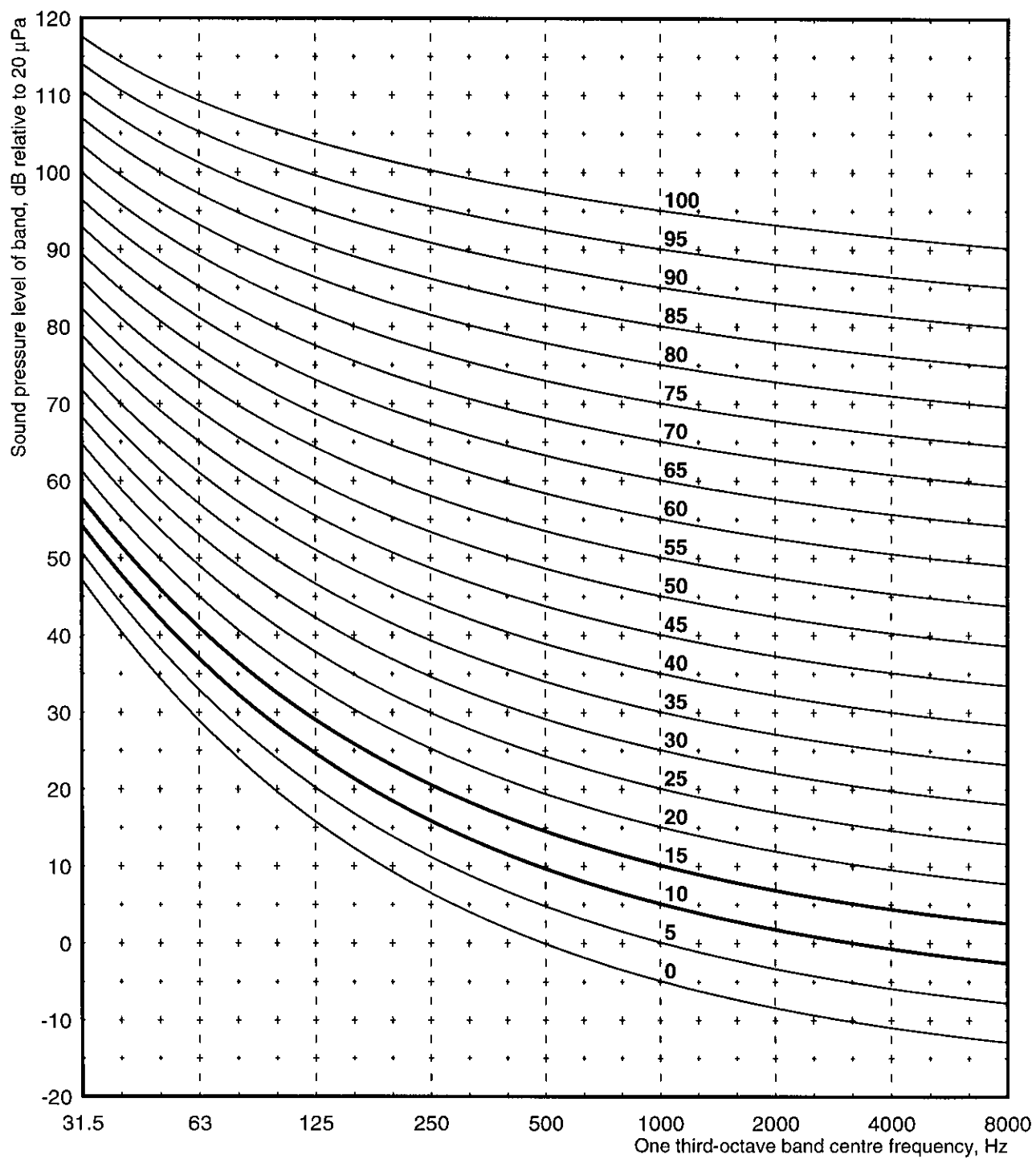


Fig. A1.2: One-third octave band Noise Rating curves.

APPENDIX 2

Derivation of Analytic Function for Octave Band Noise Rating Curves

The centre frequency of each of the octave or third-octave bands has an ISO number, B , given by

$$B = 10\log_{10}(\text{frequency})$$

This band number forms a convenient independent variable for the function. Because all common noise criteria are hyperbolic, that is, they have higher numerical values at lower frequencies, the form of the function is conveniently expressed as some function of $1/B$...

$$\phi(B) = a_n/B^n + a_{n-1}/B^{n-1} + \dots + a_1/B + a_0$$

In order to derive coefficients for these functions, a short computer program was developed, incorporating a simple curve-fitting algorithm. The algorithm used a least squares calculation to derive multiplier and regression coefficients for different orders of equation. Because the input data was available only as low-accuracy tables or graphs, the degree of accuracy actually achieved was somewhat difficult to judge. Curves of the third order in $1/B$ were found to give reasonable accuracy.

The resulting expression for the level, $L_{B,N}$, of the Noise Rating curve, N , in the octave band B is:

$$\begin{aligned} L_{B,N} = & (4354.1N - 332010)/B^3 \\ & - (680.2N - 56555)/B^2 \\ & + (24.615N - 141.1)/B \\ & + 0.77264N - 3.3532 \quad \text{dB} \end{aligned}$$

Some investigation was carried out into the necessary order of the expressions in N . It was found that a first-order expression was clearly adequate.

For computational efficiency (avoiding excessive division by powers of B), this can be written as:

$$L_{B,N} = (((aN + b)/B + cN + d)/B + eN + f)/B + gN + h \quad \text{dB}$$

APPENDIX 3

Derivation of Analytic Function for One-third Octave Band Noise Rating Curves

Technically, one-third octave versions of the ISO NR curves could never have existed. The ISO specification applied only to octave-band analysis. However, the need to measure, specify and compare NR curves with other data in one-third octave bands arises very frequently.

In the past, it has been (pragmatically) assumed that subtracting 5 dB (actually 4.77 dB — the logarithm of the effective difference in noise bandwidths) from the octave band curves gives a reasonable approximation. Indeed, at higher frequencies this is the case. However, at lower frequencies, and especially at the low noise levels common in broadcasting areas, the steep gradient of the curves leads to significant errors, amounting to about 3 dB (at NR20 and 50 Hz). This may appear to be a relatively small difference but it can significantly alter the shape of a curve when applied over a reasonably wide band of frequencies.

The error arises from the logarithmic summation of sound energy. The maximum low-frequency gradient permissible in one-third octave 'NR curves' is smaller, so that when summed into octave bands, the lowest of the three one-third octave bands does not dominate the result.

A number of methods for the derivation of the one-third octave NR data were tested. All were based (directly or indirectly) on the table of octave-band values in the original standard¹. An iterative process was used to refine an estimate, according to the errors which arose when the resulting one-third octave curve was converted back to octave values by energy summation.

The data array resulting from these calculations was used in the same way as for the octave band data to calculate analytic functions.

The resulting expression for the level $L_{B,N}$ of the Noise Rating curve, N , in the one-third octave band B is:

$$\begin{aligned} L_{B,N} = & (3775.1N - 300780)/B^3 \\ & - (590.77N - 50412)/B^2 \\ & + (20.843N - 1140)/B \\ & + 0.82136N - 11.734 \quad \text{dB} \end{aligned}$$

When converted to octave bands, this expression gives results well within the resolution of the original ISO R 1996 table.